How an Organism’s Genotype Determines Its Phenotype

- An organism’s *genotype* is its genetic makeup, the sequence of nucleotide bases in DNA.
- The *phenotype* is the organism’s physical traits, which arise from the actions of a wide variety of proteins.

DNA specifies the synthesis of proteins in two stages:

1. **transcription**, the transfer of genetic information from DNA into an RNA molecule and
2. **translation**, the transfer of information from RNA into a protein.
How an Organism’s Genotype Determines Its Phenotype

- The major breakthrough in demonstrating the relationship between genes and enzymes came in the 1940s from the work of American geneticists George Beadle and Edward Tatum with the bread mold *Neurospora crassa*.

- Beadle and Tatum
  - studied strains of mold that were unable to grow on the usual growth medium,
  - determined that these strains lacked an enzyme in a metabolic pathway that synthesized arginine,
  - showed that each mutant was defective in a single gene, and
  - hypothesized that the function of an individual gene is to dictate the production of a specific enzyme.
The one gene–one enzyme hypothesis has since been modified.

The function of a gene is to dictate the production of a polypeptide.

A protein may consist of two or more different polypeptides.

Genetic information in DNA is

- transcribed into RNA, then
- translated into polypeptides,
- which then fold into proteins.

What is the language of nucleic acids?

- In DNA, it is the linear sequence of nucleotide bases.
- A typical gene consists of thousands of nucleotides in a specific sequence.

When a segment of DNA is transcribed, the result is an RNA molecule.

RNA is then translated into a sequence of amino acids in a polypeptide.
From Nucleotides to Amino Acids: An Overview

- Experiments have verified that the flow of information from gene to protein is based on a triplet code.

- A **codon** is a triplet of bases, which codes for one amino acid.

The Genetic Code

- The **genetic code** is the set of rules that convert a nucleotide sequence in RNA to an amino acid sequence.

- Of the 64 triplets,
  - 61 code for amino acids and
  - 3 are stop codons, instructing the ribosomes to end the polypeptide.
The Genetic Code

- Because diverse organisms share a common genetic code, it is possible to program one species to produce a protein from another species by transplanting DNA.

Transcription: From DNA to RNA

- Transcription
  - makes RNA from a DNA template,
  - uses a process that resembles the synthesis of a DNA strand during DNA replication, and
  - substitutes uracil (U) for thymine (T).
Transcription: From DNA to RNA

- RNA nucleotides are linked by the transcription enzyme RNA polymerase.
**Initiation of Transcription**

- The “start transcribing” signal is a nucleotide sequence called a **promoter**, which is
  - located in the DNA at the beginning of the gene and
  - a specific place where RNA polymerase attaches.
- The first phase of transcription is initiation, in which
  - RNA polymerase attaches to the promoter and
  - RNA synthesis begins.

**RNA Elongation**

- During the second phase of transcription, called elongation,
  - the RNA grows longer and
  - the RNA strand peels away from its DNA template.

**Termination of Transcription**

- During the third phase of transcription, called termination,
  - RNA polymerase reaches a special sequence of bases in the DNA template called a **terminator**, signaling the end of the gene,
  - polymerase detaches from the RNA and the gene, and
  - the DNA strands rejoin.

**The Processing of Eukaryotic RNA**

- In the cells of prokaryotes, RNA transcribed from a gene immediately functions as **messenger RNA (mRNA)**, the molecule that is translated into protein.
- The eukaryotic cell
  - localizes transcription in the nucleus and
  - modifies, or processes, the RNA transcripts in the nucleus before they move to the cytoplasm for translation by ribosomes.
RNA processing includes
- adding a **cap** and **tail** consisting of extra nucleotides at the ends of the RNA transcript,
- removing **introns** (noncoding regions of the RNA), and
- RNA splicing, joining **exons** (the parts of the gene that are expressed) together to form **messenger RNA** (mRNA).

RNA splicing is believed to play a significant role in humans
- in allowing our approximately 21,000 genes to produce many thousands more polypeptides and
- by varying the exons that are included in the final mRNA.

Translation is the conversion from the nucleic acid language to the protein language.
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<th>Transcription</th>
<th>Translation</th>
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<td>nucleotide (ribose)</td>
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<td>RNA polymerase</td>
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<td>origin of replication</td>
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<td>start site</td>
</tr>
<tr>
<td><strong>termination site</strong></td>
<td>none</td>
<td>terminator</td>
<td>1 of 3 stop codons</td>
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**Messenger RNA (mRNA)**

- Translation requires
  - mRNA,
  - ATP,
  - enzymes,
  - ribosomes, and
  - transfer RNA (tRNA).
Transfer RNA (tRNA)

- Transfer RNA (tRNA)
  - acts as a molecular interpreter,
  - carries amino acids, and
  - matches amino acids with codons in mRNA using **anticodons**, a special triplet of bases that is complementary to a codon triplet on mRNA.

Ribosomes

- Ribosomes are organelles that
  - coordinate the functions of mRNA and tRNA and
  - are made of two subunits.
- Each subunit is made up of
  - proteins and
  - a considerable amount of another kind of RNA, **ribosomal RNA (rRNA)**.
- A fully assembled ribosome holds tRNA and mRNA for use in translation.
Translation: The Process

- Translation is divided into three phases:
  1. initiation,
  2. elongation, and
  3. termination.
Initiation

- Initiation brings together
  - mRNA,
  - the first amino acid with its attached tRNA, and
  - two subunits of the ribosome.
- The mRNA molecule has a cap and tail that help the mRNA bind to the ribosome.

Initiation occurs in two steps.
1. An mRNA molecule binds to a small ribosomal subunit, then a special initiator tRNA binds to the **start codon**, where translation is to begin on the mRNA.
2. A large ribosomal subunit binds to the small one, creating a functional ribosome.
Elongation

- Elongation occurs in three steps.
  - **Step 1: Codon recognition.** The anticodon of an incoming tRNA pairs with the mRNA codon at the A site of the ribosome.

– Step 2: Peptide bond formation.
  - The polypeptide leaves the tRNA in the P site and attaches to the amino acid on the tRNA in the A site.
  - The ribosome catalyzes the bond formation between the two amino acids.
**Elongation**

- **Step 3: Translocation.**
  - The P site tRNA leaves the ribosome.
  - The tRNA carrying the polypeptide moves from the A to the P site.

**Termination**

- Elongation continues until
  - a **stop codon** reaches the ribosome’s A site,
  - the completed polypeptide is freed, and
  - the ribosome splits back into its subunits.
Review: DNA → RNA → Protein

- In a cell, genetic information flows from
  - DNA to RNA in the nucleus and
  - RNA to protein in the cytoplasm.
Review: DNA → RNA → Protein

- As it is made, a polypeptide
  - coils and folds and
  - assumes a three-dimensional shape, its tertiary structure.

- Transcription and translation are how genes control the structures and activities of cells.
Mutations

- A **mutation** is any change in the nucleotide sequence of DNA.
- Mutations can change the amino acids in a protein.
- Mutations can involve
  - large regions of a chromosome or
  - just a single nucleotide pair, as occurs in sickle-cell disease.

**Types of Mutations**

- Mutations within a gene can be divided into two general categories:
  1. nucleotide substitutions (the replacement of one base by another) and
  2. nucleotide deletions or insertions (the loss or addition of a nucleotide).
- Insertions and deletions can
  - change the reading frame of the genetic message and
  - lead to disastrous effects.
Figure 10.22a

(a) Base substitution

Figure 10.22b

(b) Nucleotide deletion

Figure 10.22c

(c) Nucleotide insertion

Mutations

- (1) Wild-type gene
  - The big red pig ate the red rag.
- (2) Base substitution
  - The big res pig ate the red rag.
- (3) Base addition
  - The big res dpi gat eth ere dra g.
- (4) Base deletion
  - The big re-p iga tet her edr ag.

3 and 4 are known as frameshift mutations since everything after the mutation is shifted and would likely code for a new sequence of AAs.
**Mutagens**

- Mutations may result from
  - errors in DNA replication or recombination or
  - physical or chemical agents called **mutagens**.
- Mutations
  - are often harmful but
  - are useful in nature and the laboratory as a source of genetic diversity, which makes evolution by natural selection possible.

**VIRUSES AND OTHER NONCELLULAR INFECTIOUS AGENTS**

- Viruses share some, but not all, characteristics of living organisms. Viruses
  - possess genetic material in the form of nucleic acids wrapped in a protein coat,
  - are not cellular, and
  - cannot reproduce on their own.

**Animal Viruses**

- Viruses that infect animals cells
  - are a common cause of disease and
  - may have RNA or DNA genomes.
- Many animal viruses have an outer envelope made of phospholipid membrane, with projecting spikes of protein.
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